

CHAPTER 4

Fluid mechanics

Fluids play a vital role in many aspects of everyday life. We drink them, breathe them, and swim in them; they circulate through our bodies, they control our weather, airplanes fly through them, and ships float in them. A **fluid** is any substance that can flow; we use the term for both liquids and gases. Usually, gases are easily compressed while liquids are quite incompressible. We begin our study with **fluid statics**, the study of fluids at rest (in equilibrium). The key concepts include density, pressure and buoyancy. **Fluid dynamics** is the study of fluids in motion. Fluid dynamics is much more complex and indeed is one of the most complex branches of mechanics.

4.1

Fluid statics

The branch of physics dealing with the properties of fluids at rest is known as **fluid statics** or **hydrostatics**.

Fluid pressure

The pressure of a fluid at a point inside it is defined to be the magnitude of the normal force (or thrust) exerted by the fluid on a unit area about that point.

$$\text{Pressure} = \frac{\text{Thrust}}{\text{Area}} = \frac{\text{Force}}{\text{Area}}$$

SI unit of pressure : $1 \text{ Pa} = 1 \text{ N/m}^2$

A common unit of pressure is the atmosphere (atm), i.e., the pressure exerted by the atmosphere at sea level, **$1 \text{ atm} = 1.013 \times 10^5 \text{ Pa}$; $1 \text{ Bar} = 10^5 \text{ Pa}$; $1 \text{ atm} = 760 \text{ mm of Hg} = 76 \text{ cm of Hg}$**

Another common unit of pressure is pounds/inch² (lb/in.²), also called '**psi**'. We are accustomed to the '30 – 35 psi' pressure within our car's tyres.

$1 \text{ atm} = 14.7 \text{ psi}$; $1 \text{ psi} \approx 6895 \text{ Pa}$; $1 \text{ mm of Hg} = 1.934 \times 10^{-2} \text{ psi}$

- Pressure is a scalar quantity. Always remember, it is the component of the force normal (perpendicular) to the area under consideration for calculating pressure, not the force vector.

Blood pressure in human body is also measured in 'mm of Hg'. Pressure of flowing blood in major arteries is approx. 120 mm of Hg, when heart is contracted to its smallest size (systolic pressure). When the heart expands to its largest size, the pressure is about 80 mm of Hg (diastolic pressure).

Pascal's law

Fluids can exert pressure on the base and walls of the container in which they are enclosed.

- The French scientist Blaise Pascal observed that 'the pressure in a fluid at rest is the same at all points if they are at the same height'. This is called '**Pascal's law**'.

Fluid pressure acts in all directions, not just the direction of the applied force. When you inflate a car tyre, you are increasing the pressure in the tyre. This force acts up, down, and sideways in all directions inside the tyre.

- The fluid pressure at any point on the object is perpendicular to the surface of the object at that point (see fig. 1).
'Pressure applied to any part of an enclosed fluid at rest is transmitted in all directions equally to every portion of fluid and the walls of the containing vessel.' This is another statement of **Pascal's law** and this property is used in hydraulic press ; hydraulic lift ; hydraulic brakes in cars, trucks.

If p_1 is the pressure on the surface of liquid (see fig. 2) and p_2 is the pressure at a point within the liquid at a depth h , then, their pressure difference ($p_2 - p_1$) is given by,

$$\Delta p = p_2 - p_1 = \rho g h$$

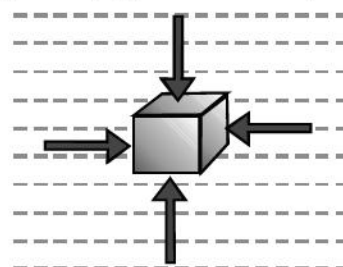


Fig. 1 Fluid pressure acts perpendicular to the surface of the object

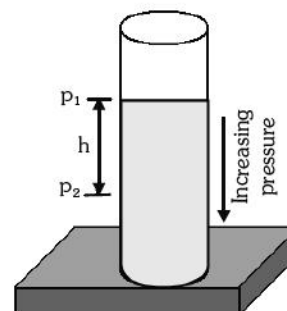


Fig. 2 Pressure inside fluid increases with depth

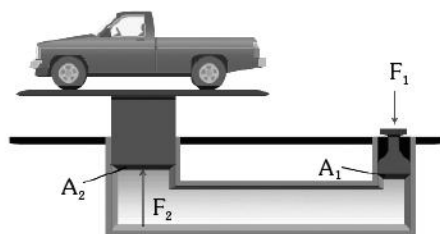


Fig.3 A hydraulic lift

The pressure is the same on both sides of the enclosed fluid, allowing a small force to lift a heavy object.

$$\text{Pressure, } P = \frac{F_1}{A_1} = \frac{F_2}{A_2} \quad \text{or} \quad F_2 = \left(\frac{A_2}{A_1} \right) F_1$$

Since, $A_2 > A_1$, $F_2 > F_1$.

- The pressure depends only on the height of the column of fluid above the surface where you measure the pressure. It does not depend on the area of the surface in contact or the shape of the liquid column. The greater the height of the column of fluid above a surface, the greater the pressure exerted by the fluid on the surface.
- Thickness of wall of the dam gradually increases as the depth increases. This is because pressure increases with the depth and to withstand great pressure, the thickness of the wall should be more.

The total force on a dam in which water is filled to a height H behind a dam of width W is given by (see fig.5),

$$F = \frac{1}{2} \rho g W H^2$$

Absolute pressure

When pressure is measured above zero pascal (absolute zero or complete vacuum), it is called absolute pressure.

Gauge pressure (P_g)

When the pressure is measured above the atmospheric pressure, it is called gauge pressure.

Absolute pressure, $OB = OA + AB$

$$\text{or } P_{\text{absolute}} = P_{\text{atm}} + P_g$$

- All pressure gauges read zero when open to atmosphere. They read the pressure difference between fluid pressure and the atmospheric pressure. It is measured by a 'pressure gauge'.

Vacuum pressure (P_v)

It is the pressure of a fluid below the atmospheric pressure. Its value is the amount by which it is below the atmospheric pressure. It is measured by a 'vacuum gauge'.

Absolute pressure, $OC = OA - AC$

$$\text{or } P_{\text{absolute}} = P_{\text{atm}} - P_v$$

Equilibrium of two immiscible liquids in a U tube

Let two immiscible liquids of different densities be poured into the two limbs of a U tube (see fig.7). Suppose that, when the liquids are at rest, D is their surface of separation and A and C are their free surfaces. The horizontal plane through D intersects the other limb at E .

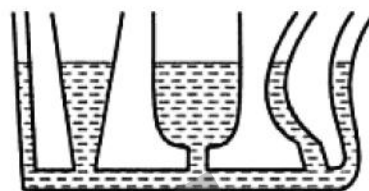


Fig.4 Hydrostatic paradox : Pressure at the bottom of each section of the vessel is same

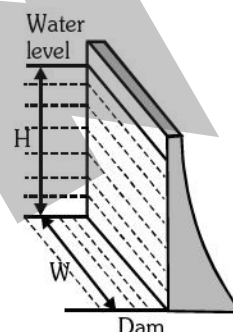
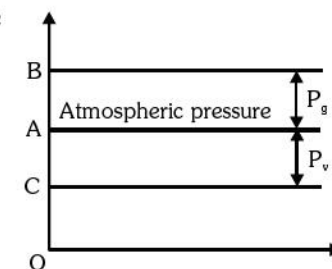


Fig.5



O represents 0 pascal (absolute vacuum)
 $AB = \text{Gauge pressure} = P_g$
 $AC = \text{Vacuum pressure} = P_v$
 $OA = \text{Atmospheric pressure} = P_a$

Fig.6

At equilibrium, the pressures at D and E will be equal. The pressure at D is (see fig. 7) $P + \rho_1 g h_1$ and that at E is $P + \rho_2 g h_2$. Here P is the atmospheric pressure. Therefore, $P + \rho_1 g h_1 = P + \rho_2 g h_2$

$$\text{or } \frac{h_1}{h_2} = \frac{\rho_2}{\rho_1}$$

That is, at equilibrium, the heights of the two liquid columns above the common surface of contact are in the inverse ratio of their densities. The height of the heavier liquid will be smaller.

Note that the height of the liquid column does not depend on the cross-sectional area of the limb of the U tube. That is, the above equation will also hold if the two limbs have unequal diameters.

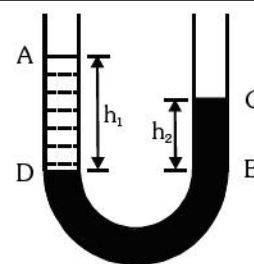


Fig. 7

NUMERICAL CHALLENGE 4.1

In a car lift used in a service station, compressed air exerts a force on a small piston that has a circular cross-section and a radius of 5.00 cm. This pressure is transmitted by a liquid to a piston that has a radius of 15.0 cm. What force must the compressed air exert to lift a car weighing 13,275 N? What air pressure produces this force?

Solution

Area of small piston, $A_1 = \pi r_1^2 = \pi(5)^2 = 25\pi \text{ cm}^2$; area of large piston, $A_2 = \pi r_2^2 = \pi(15)^2 = 225\pi \text{ cm}^2$; force on large piston, $F_2 = \text{weight of the car} = 13,275 \text{ N}$; force on small piston, $F_1 = ?$

According to Pascal's law, the pressure is transmitted equally in all direction within the fluid, thus,

$$\text{Pressure, } P = \frac{F_1}{A_1} = \frac{F_2}{A_2} \quad \text{or} \quad F_1 = \left(\frac{A_1}{A_2}\right) F_2 = \left(\frac{25\pi}{225\pi}\right) (13275) = 1475 \text{ N}$$

The air pressure that produces this force is,

$$P = \frac{F_1}{A_1} = \frac{1475 \text{ N}}{25\pi \times 10^{-4} \text{ m}^2} = 1.878 \times 10^5 \text{ Pa}$$

NUMERICAL CHALLENGE 4.2

In a huge oil tanker, salt water has flooded an oil tank to a depth of 5.00 m. On top of the water is a layer of oil 8.00 m deep (see fig. 8). The oil has a density of 700 kg/m^3 . Find the pressure at the bottom of the tank. (Take 1020 kg/m^3 as the density of salt water, air pressure as $1.01 \times 10^5 \text{ Pa}$, $g = 10 \text{ m/s}^2$)

Solution

Given, height of layer of oil, $h_1 = 8 \text{ m}$; density of oil, $\rho_1 = 700 \text{ kg/m}^3$; height of layer of water, $h_2 = 5 \text{ m}$; density of salt water, $\rho_2 = 1020 \text{ kg/m}^3$; air pressure, $P_0 = 1.01 \times 10^5 \text{ Pa}$.

Pressure at the bottom of the oil layer, $P_1 = P_0 + \rho g h_1$

$$\begin{aligned} \text{or } P_1 &= 1.01 \times 10^5 + (700)(10)(8) \\ &= 1.01 \times 10^5 + 0.56 \times 10^5 \text{ Pa} \\ &= 1.57 \times 10^5 \text{ Pa} \end{aligned}$$

Pressure at the bottom of the water layer, $P_2 = P_1 + \rho g h_2$

$$\begin{aligned} \text{or } P_1 &= 1.57 \times 10^5 + (1020)(10)(5) \\ &= 1.57 \times 10^5 + 0.51 \times 10^5 \text{ Pa} \\ &= 2.08 \times 10^5 \text{ Pa} \end{aligned}$$

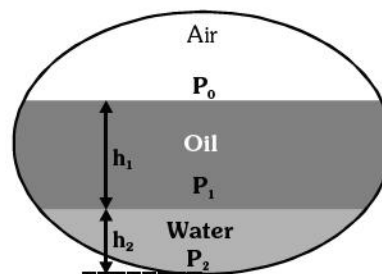


Fig. 8 Numerical challenge 4.2

4.2

Measurement of pressure

Atmospheric pressure

Atmospheric pressure is the pressure exerted on a surface by the weight of the atmosphere above the surface.

The air that surrounds Earth is called **atmosphere**. The layer of gases closest to Earth's surface is called the **troposphere**. The troposphere is between 8 and 18 kilometers thick. The troposphere contains 99% of the air in the atmosphere. The air is densest in this layer.

As the height above Earth increases, the number of particles of gas in the layers of the atmosphere decreases. The air gradually thins off into space. The highest layer, which is called the exosphere, ends at about 700 kilometers above Earth's surface. In this layer, negligibly small number of gas particles are present.

If you hold your hand out in front of you, Earth's atmosphere exerts a downward force on your hand due to the weight of the atmosphere above it.

Altitude and air pressure

The particles of gas press on Earth's surface and on everything they surround. The force put on a given area by the weight of the air above it is called **air pressure** or **atmospheric pressure**. As you go higher in the atmosphere, the height of air column above you decreases. Thus, the weight of air above you decreases. Hence, the air pressure above you decreases. **Air pressure decreases with higher altitude.**

Mercury barometer

It is an instrument used to find the atmospheric pressure at any place. It consists of an evacuated glass tube put in a reservoir of mercury. Atmospheric pressure pushes mercury up in the tube. The mercury reaches a height where the pressure at the bottom of the column of mercury balances the pressure of the atmosphere.

Using formula, $P = \rho g h$ or $h = P/\rho g$, we can find the height of mercury column in the glass tube, which is,

$$760 \text{ mm of Hg} = 76 \text{ cm of Hg} = 1 \text{ atm}$$

- Mercury is used in barometer because its density is high, thus, height of mercury column will be low ($h \propto 1/\rho$). If we use water in the barometer, then height of water will be 10.33 metre which is impractical.

Another unit of pressure is 'Torr'. **1 torr = 1 mm of Hg**

Manometers

Measuring pressure usually involves the use of liquid columns in vertical or inclined tubes. Pressure measuring devices based on this technique are called **manometers**. The mercury barometer is also an example of one type of manometer, but there are many other designs possible. Three common types of manometers include the piezometer tube, the U-tube manometer, and the inclined-tube manometer.

Piezometer tube

The simplest type of manometer consists of a vertical tube, open at the top, and attached to the container in which the pressure is to be measured (see fig. 11). Since manometers involve columns of fluids at rest, the fundamental equation describing their use is $P = P_0 + \rho g h$ which gives the pressure at any elevation within a homogeneous fluid in terms of a reference pressure (P_0) and the vertical distance h between P and P_0 .

Layers of Atmosphere	
Exosphere	700 km
Thermosphere	640 km
Mesosphere	80 km
Stratosphere	50 km
Troposphere	8 - 18 km
	0 km

Fig.9 The atmosphere forms five layers of gases around Earth.

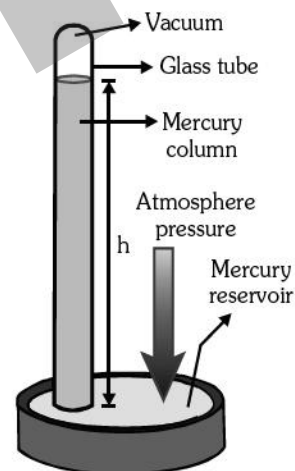


Fig.10 Mercury barometer

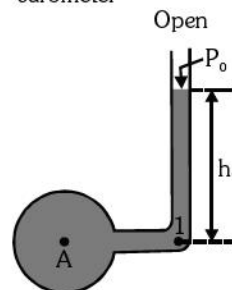


Fig.11 A piezometer tube

Remember that in a fluid at rest, pressure will increase as we move downward and will decrease as we move upward. Application of this equation to the piezometer tube of Fig.11 indicates that the pressure P_A can be determined by a measurement of h_1 through the relationship

$$P_A = P_1 = P_0 + \rho g h_1$$

(Point 1 and point A within the container are at the same horizontal level, thus, $P_A = P_1$)

Here, ρ is the density of the liquid in the container. Since the tube is open at the top, the pressure P_0 can be set equal to zero. In that case $P_A = \rho g h_1$, this is basically the 'gauge pressure', with the height h_1 measured from the upper surface to point 1.

- Although the piezometer tube is a very simple and accurate pressure measuring device, it has several disadvantages. It is only suitable if the pressure in the container is greater than atmospheric pressure (otherwise air would be sucked into the system), and the pressure to be measured must be relatively small so the required height of the column is reasonable. Also, the fluid in the container in which the pressure is to be measured must be a liquid rather than a gas.
- An important device whose operation is based upon the principle used in a piezometric tube is 'sphygmomanometer', the traditional instrument used to measure blood pressure.

Sphygmomanometer

Blood pressure is measured with a sphygmomanometer (see fig. 12).

The oldest kind of sphygmomanometer consists of a mercury manometer on one side attached to a closed bag—the cuff. The cuff is wrapped around the upper arm at the level of the heart. A rubber bulb forces air into a cuff and simultaneously into a manometer. The manometer measures the gauge pressure of the air in the cuff. At first, the pressure in the cuff is higher than the systolic pressure—the maximum pressure in the brachial artery that occurs when the heart contracts. The cuff pressure squeezes the artery closed and no blood flows into the forearm. A valve on the cuff is then opened to allow air to escape slowly. The measurer listens with a stethoscope to the artery at a point just below the cuff. When the cuff pressure decreases to just below the systolic pressure, a little amount of blood flows past the constriction in the artery with each heartbeat. The sound of turbulent blood flow past the constriction can be heard through the stethoscope. The manometer is calibrated to read the pressure in millimeters of mercury, and the value obtained is about 120 mm for a normal heart. Values of 130 mm or above are considered high, and medication to lower the blood pressure is often prescribed for such patients. As air continues to escape from the cuff, the sound of blood flowing through the constriction in the artery continues to be heard. When the pressure in the cuff reaches the diastolic pressure in the artery—the minimum pressure that occurs when the heart muscle is relaxed—there is no longer a constriction in the artery, so the pulsing sounds cease. At this point, continuous sounds of blood flow are heard. In the normal heart, this transition occurs at about 80 mm of mercury, and values above 90 require medical intervention. Blood pressure readings are usually expressed as the ratio of the systolic pressure to the diastolic pressure, which is 120/80 for a healthy heart.

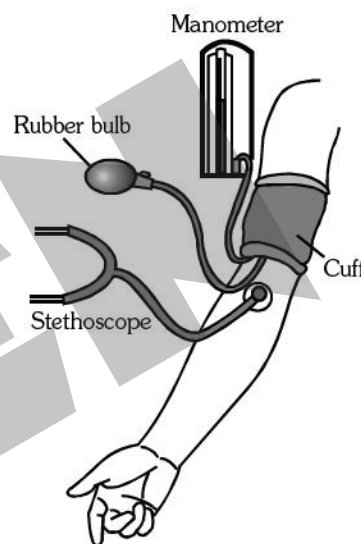


Fig. 12 A sphygmomanometer measures blood pressure.

U-tube manometer

To overcome the difficulties noted in piezometric tube, another type of manometer which is widely used consists of a tube formed into the shape of a U (see fig. 13). The fluid in the manometer is called the gauge fluid. One commonly used U-tube manometer consists of mercury as fluid. The pressure at point A and point 1 are the same, and as we move from point 1 to point 2, the pressure will increase by $\rho_1 g h_1$, ρ_1 is the density of fluid inside the vessel. The pressure at point 2 is equal to the pressure at point 3, since the pressures at same horizontal levels in a continuous mass of fluid at rest must be the same. Note that we could not simply "jump across" from point 1 to a point at the same horizontal level in the right-hand tube since these would not be points within the same continuous mass of fluid. With the pressure at point 3 specified, we now move to the open end where the pressure is P_0 .

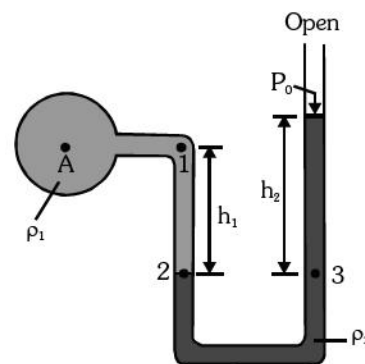


Fig. 13 A U-tube manometer

As we move vertically upward the pressure decreases by an amount $\rho_2 gh_2$, where ρ_2 is the density of gauge fluid. In equation form these various steps can be expressed as,

$$P_A + \rho_1 gh_1 = P_0 + \rho_2 gh_2$$

$$\text{or } P_A = P_0 + \rho_2 gh_2 - \rho_1 gh_1 \text{ ---- (1) (This is absolute pressure)}$$

If we put P_0 as zero, we get,

$$P_A = \rho_2 gh_2 - \rho_1 gh_1 \text{ ---- (2) (This is gauge pressure)}$$

- A major advantage of the U-tube manometer lies in the fact that the gauge fluid can be different from the fluid in the container in which the pressure is to be determined. The fluid in vessel A can be either a liquid or a gas. If A does contain a gas, the contribution of the gas column $\rho_1 gh_1$ is almost always negligible so that $P_A = P_2$ and in this instance eq.(1) becomes,

$$P_A = P_0 + \rho_2 gh_2$$

Similarly, eq.(2), becomes, $P_A = \rho_2 gh_2$ (for $P_0 = 0$)

Thus, from the above equation we can conclude that, for a given pressure, the height h_2 is governed by the density ρ_2 of the gauge fluid used in the manometer.

- If the pressure is large, then a heavy gauge fluid, such as mercury, can be used and a reasonable column height (not too long) can still be maintained. Alternatively, if the pressure is small, a lighter gauge fluid, such as water, can be used so that a relatively large column height (which can be easily read) can be achieved.

The fig. 14 shown below consists of a gas inside the vessel, thus, the contribution of the gas column is negligible. Fig. 14(a) shows 'gauge pressure', a pressure greater than the atmospheric pressure. Fig. 14(b) shows 'vacuum pressure', a pressure below the atmospheric pressure.

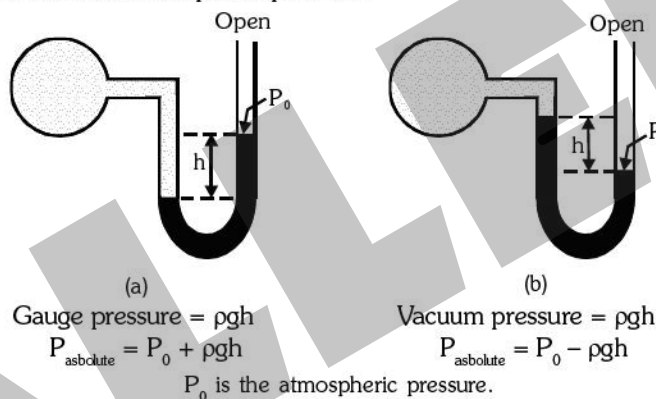


Fig.14 A U-tube manometer consisting of gas inside the given vessel

- **Aneroid barometer** is also a pressure gauge that is used to measure the pressure inside a fluid.

NUMERICAL CHALLENGE 4.3

A manometer is attached to a container of gas to determine its pressure. Before the container is attached, both sides of the manometer are open to the atmosphere. After the container is attached, the mercury on the side attached to the gas container rises 12 cm above its previous level (see fig.15). What is the absolute pressure of the gas in Pa? Atmospheric pressure, $P_0 = 1.01 \times 10^5 \text{ Pa}$; $g = 9.8 \text{ m/s}^2$; density of mercury, $\rho = 13600 \text{ kg/m}^3$.

Solution

The mercury column is higher on the side connected to the container of gas, so we know that the pressure of the enclosed gas is lower than atmospheric pressure i.e., it is vacuum pressure. We need to find the difference in levels of the mercury columns on the two sides. It is not 12 cm. If one side went up by 12 cm, then the other side has gone down by 12 cm, since the same volume of mercury is contained in the manometer. Thus, the difference in the mercury levels is 24 cm i.e., $h = 24 \text{ cm} = 0.24 \text{ m}$

$$\text{Absolute pressure, } P_{\text{absolute}} = P_0 - \rho gh = 1.01 \times 10^5 - 13600 \times 9.8 \times 0.24$$

$$= 1.01 \times 10^5 - 0.32 \times 10^5 = \mathbf{6.9 \times 10^4 \text{ Pa}}$$

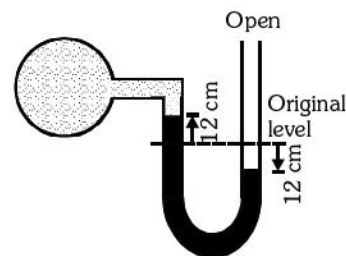


Fig.15 Numerical challenge 4.3

NUMERICAL CHALLENGE 4.4

A woman's systolic blood pressure when resting is 160 mm Hg. What is this pressure in,

- (a) Pa (b) lb/in² (psi) (c) atm (d) torr ?

Solution

- (a) We know that, density of mercury, $\rho = 13600 \text{ kg/m}^3$; $g = 9.8 \text{ m/s}^2$.

Given, height of mercury column, $h = 160 \text{ mm} = 0.160 \text{ m}$

$$\text{Pressure, } P = \rho gh = 13600 \times 9.8 \times 0.160 = \mathbf{2.132 \times 10^4 \text{ Pa}}$$

- (b) We know that, $1 \text{ mm of Hg} = 1.934 \times 10^{-2} \text{ psi}$
or $160 \text{ mm of Hg} = 160 \times 1.934 \times 10^{-2} \text{ psi} = \mathbf{3.0944 \text{ psi}}$

- (c) We know that, $760 \text{ mm of Hg} = 1 \text{ atm}$
or $1 \text{ mm of Hg} = (1/760) \text{ atm}$
or $160 \text{ mm of Hg} = (1/760) \times 160 \text{ atm} = \mathbf{0.2105 \text{ atm}}$

- (d) $1 \text{ mm of Hg} = 1 \text{ torr}$

Thus, pressure = 160 mm of Hg = **160 torr**

NUMERICAL CHALLENGE 4.5

When a mercury manometer is connected to a gas main, the mercury stands 40.0 cm higher in the tube that is open to the air than in the tube connected to the gas main. A barometer at the same location reads 74.0 cm of Hg. Determine the absolute pressure of the gas in cm of Hg.

Solution

Since, the mercury stands higher in the tube that is open to the air, the pressure of the gas is 'gauge pressure', a pressure above the atmospheric pressure [refer fig. 14(a)].

Thus, absolute pressure, $P_{\text{absolute}} = P_{\text{atmosphere}} + P_{\text{gauge}} = 74 \text{ cm of Hg} + 40 \text{ cm of Hg} = \mathbf{114 \text{ cm Hg}}$

NUMERICAL CHALLENGE 4.6

A closed tank contains compressed air and oil ($\rho_{\text{oil}} = 900 \text{ kg/m}^3$) as is shown in fig. 16. A U-tube manometer using mercury ($\rho_{\text{Hg}} = 13600 \text{ kg/m}^3$) is connected to the tank as shown. The column heights are $h_1 = 0.9 \text{ m}$, $h_2 = 0.15 \text{ m}$, $h_3 = 0.225 \text{ m}$. Determine the pressure reading in pascal of the gauge.

Solution

Following the general procedure of starting at one end of the manometer system and move to the other end, let us start at the air-oil interface in the tank and proceed to the open end where the pressure (P_0) is taken zero as we have to find gauge pressure. The pressure at level 1 is given by,

$$P_1 = P_{\text{air}} + \rho_{\text{oil}} g (h_1 + h_2) \text{ ---- (1)}$$

This pressure is equal to the pressure at level 2, since these two points are at the same horizontal level in a homogeneous fluid at rest. That is,

$$P_1 = P_2 = P_{\text{air}} + \rho_{\text{oil}} g (h_1 + h_2) \text{ ---- (2)}$$

As we move from level 2 to the open end, the pressure must decrease by $\rho_{\text{Hg}} g h_3$ and at the open end the pressure (P_0) is taken zero. Thus, the manometer equation can be expressed as,

$$P_2 - \rho_{\text{Hg}} g h_3 = P_0$$

$$\text{or } P_{\text{air}} + \rho_{\text{oil}} g (h_1 + h_2) - \rho_{\text{Hg}} g h_3 = 0$$

$$\text{or } P_{\text{air}} = \rho_{\text{Hg}} g h_3 - \rho_{\text{oil}} g (h_1 + h_2)$$

$$= 13600 \times 9.8 \times 0.225 - 900 \times 9.8 \times (0.9 + 0.15) = 2.9988 \times 10^4 - 0.9261 \times 10^4$$

$$= \mathbf{2.0727 \times 10^4 \text{ Pa}}$$

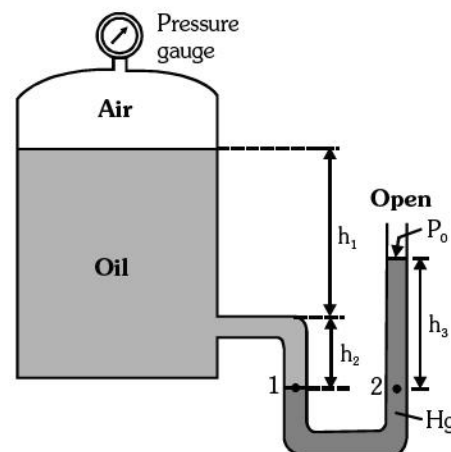


Fig. 16 Numerical challenge 4.6

4.3

Buoyancy

The tendency for an immersed body to be lifted up in a fluid, due to an upward force that acts opposite to the action of gravity is called buoyancy.

The buoyant force

It is an upward force that is exerted by a fluid on any object immersed partly or wholly in the fluid.

Archimedes' principle

According to Archimedes' principle, 'any object completely or partially submerged in a fluid experiences an upward buoyant force equal in magnitude to the weight of the fluid displaced by the object'.

Apparent weight

Because of an upward force acting on a body immersed in a fluid, either wholly or partially, there occur an apparent loss in weight of the body. The net weight of an object immersed in a fluid is called 'apparent weight'.

Sinking and floating

The buoyant force pushes an object in a fluid upward, but gravity pulls the object downward.

- If the weight of the object is greater than the buoyant force, the net force on the object is downward and it sinks (see fig. 17)

Let an object of density ρ_s be immersed in a liquid of density ρ_L , W be the weight of object in air, F_B be the buoyant force.

- If $\rho_s > \rho_L$, the object will sink to the bottom (see fig. 17).

Apparent weight, $W' = W - F_B$

$$= M_s g - M_L g = (M_s - M_L) g = (\rho_s V_s - \rho_L V_L) g$$

$$= (\rho_s V_s - \rho_L V_s) g$$

Here, $V_s = V_L$ because the object is completely immersed in water.

$$W' = (\rho_s - \rho_L) V_s g$$

$$\text{Now, } W' = \left(1 - \frac{\rho_L}{\rho_s}\right) \rho_s V_s g$$

$$\text{Also, } W' = W \left(1 - \frac{\rho_L}{\rho_s}\right) \quad (\because \rho_s V_s g = W = \text{weight of object in air})$$

- If the buoyant force is equal to the object's weight, the forces are balanced and the object floats.

If $\rho_s = \rho_L$, apparent weight = 0 i.e.,

weight of the body in air = buoyant force

$$\text{or } W = F_B \text{ or } M_s g = M_L g \text{ or } M_s = M_L$$

$$\text{or } \rho_s V_s = \rho_L V_L \text{ or } V_s = V_L$$

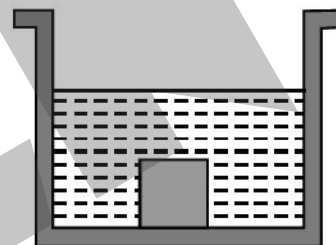
This means, the body will just float or remain hanging at whatever height it is left inside the liquid (see fig. 18).

- If $\rho_s < \rho_L$, apparent weight = 0 i.e., weight of the body in air = buoyant force
or $W = F_B$ or $M_s g = M_L g$ or $M_s = M_L$

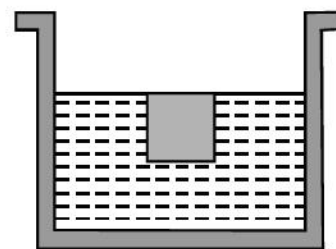
$$\text{or } \rho_s V_s = \rho_L V_L \text{ or } V_L = \frac{\rho_s V_s}{\rho_L}$$

Clearly, the volume (V_L) of liquid displaced is less than the total volume (V_s) of the body as $\rho_s < \rho_L$. This means the body will float but it is immersed partly in the liquid (see fig. 19).

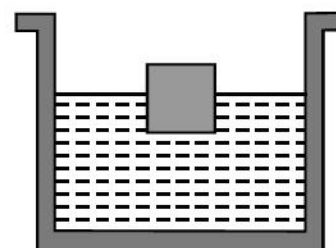
- The fraction of floating object inside a liquid, $\frac{V_L}{V_s} = \frac{\rho_s}{\rho_L}$



$\rho_s > \rho_L$
Fig. 17 The body sinks to the bottom



$\rho_s = \rho_L$
Fig. 18 The body just floats in liquid i.e., it is completely immersed in liquid



$\rho_s < \rho_L$
Fig. 19 The body floats on liquid, it is partly immersed in liquid

- The fraction of floating object outside a liquid, $\frac{V_o}{V_s} = \frac{\rho_L - \rho_s}{\rho_L}$
- Buoyant force is the loss of weight of an object when it is immersed in a liquid.

$$F_B = W_1 - W_2$$

Where, W_1 is the weight of an object in air and W_2 is its weight (apparent weight) when it is completely immersed in the liquid.

NUMERICAL CHALLENGE 4.7

A plastic sphere of radius 0.04 m and mass 0.01 kg is immersed in a container of water. It is attached to a string that is attached to the bottom of the container [see fig.20(a)]. Find the tension in the string.

(Given, density of water = 1000 kg/m³, g = 9.8 m/s²).

Solution

The buoyant force (F_B) acts upwards on the plastic sphere which is balanced by the tension (T) developed in the string and weight (W) of the sphere [see fig.20(b)], i.e.,

$$F_B = T + W$$

$$\text{or } T = F_B - W = \rho_w V_w g - m_s g = (\rho_w V_w - m_s)g \quad (1)$$

$$V_w = \text{volume of water displaced} = \text{volume of the sphere}$$

(\because Sphere is completely immersed in water)

$$\text{or } V_w = \frac{4}{3}\pi r^3 = \frac{4}{3}\pi(0.04)^3 = 2.6 \times 10^{-4} \text{ m}^3;$$

$$\text{mass of sphere, } m_s = 0.01 \text{ kg}$$

$$\begin{aligned} \text{Now, } T &= (\rho_w V_w - m_s)g = (1000 \times 2.6 \times 10^{-4} - 0.01) \times 9.8 \\ &= (0.26 - 0.01) \times 9.8 = \mathbf{2.45 \text{ N}} \end{aligned}$$

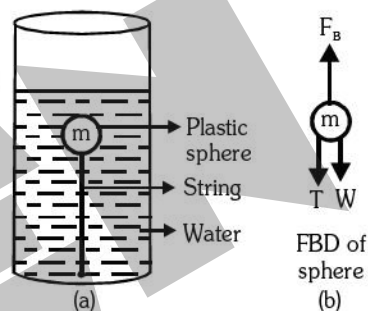


Fig.20 Numerical challenge 4.7

NUMERICAL CHALLENGE 4.8

A boat is 4.0 m wide and 6.0 m long. When a heavy object is placed in it, the boat sinks 4.00 cm in the water. What is the weight of the object? Take, density of water = 1000 kg/m³.

Solution

Length, $l = 6 \text{ m}$; width, $b = 4 \text{ m}$; depth, $h = 4 \text{ cm} = 0.04 \text{ m}$.

Volume of boat inside the water = volume of liquid displaced

$$\text{or } V = l \times b \times h = 6 \times 4 \times 0.04 = \mathbf{0.96 \text{ m}^3}$$

Due to the weight of the object, the boat further moves down in water, thus an extra buoyant force acts on the boat which must be equal to the weight of the object.

$$\text{Thus, weight of the object, } W = \text{Extra buoyant force acting on the object} = \rho_w V g = 1000 \times 0.96 \times 9.8$$

$$= \mathbf{9408 \text{ N}}$$

4.4

Relative density (or specific gravity)

Relative density is given by, $R.D. = \frac{\text{Density of object}}{\text{Density of water}} = \frac{\rho}{\rho_w}$

Also, $R.D. = \frac{W_1}{W_1 - W_2}$

Where, W_1 = weight of object in air ; W_2 = weight of object in water.

Hydrometer

A hydrometer is an instrument that measures the relative density or density of a liquid. When the hydrometer is placed in a liquid, it sinks to a certain depth. The depth to which it sinks depends on the density of the liquid. The lower the density of the liquid, the deeper the hydrometer sinks.

- **Lactometer** is also a specially designed hydrometer used to measure the relative density of milk and hence testing its purity. The relative density of milk is nearly 1.03. On adding water to milk, the resulting mixture has relative density less than 1.03. Smaller the relative density, more will the amount of water added to the milk and hence lesser will be the purity of the milk.

Melting of ice that is floating on water

When a piece of ice floating on water in a beaker completely changes (melts) to liquid state, the level of water in the beaker remains unchanged.

Let m = mass of ice ; ρ = density of water ; V = volume of water displaced

$$W = F_B \quad \text{or} \quad mg = \rho_w Vg$$

$$\text{or } m = 1 \times V \quad (\rho_w = 1 \text{ g/cm}^3) \quad \text{or} \quad m = V \quad \text{--- (1)}$$

Now, volume V' of water formed on melting,

$$V' = m/\rho = m/1 \quad \text{or} \quad V' = m \quad \text{--- (2)}$$

From (1) & (2), we get, $V' = V$, i.e., there is no change in the volume of the contents of the beaker. Hence, level of water will not change.

- Let us consider an ice cube containing a lead in it floating on water in a beaker. As ice melts, lead sinks to the bottom and the level of water in the glass falls. Let M = mass of ice cube, m = mass of lead piece. Now, weight of floating body is equal to buoyant force exerted by the liquid.

$$\text{i.e., } W = F_B \quad \text{or} \quad (M + m)g = \rho_w Vg \quad \text{or} \quad (M + m) = 1 \times V \quad (\rho_w = 1 \text{ g/cm}^3)$$

$$\text{or } M + m = V \quad \text{--- (1)}$$

$$\text{On melting, the new volume, } V' = \frac{M}{\rho} + \frac{m}{\rho'} = \frac{M}{1} + \frac{m}{\rho'} \quad \text{or} \quad V' = M + (m/\rho_{\text{Lead}}) \quad \text{--- (2)} \quad [\rho_{\text{Lead}} > 1]$$

Now, clearly m/ρ_{Lead} will be less than m , thus using (1) & (2), $V' < V$. Hence, level of water falls in the beaker.

4.5

***Equilibrium of floating bodies**

For a floating body in equilibrium, there are two necessary conditions :

- (1) The weight of the body W must be equal to the buoyant force F_B .
- (2) The centre of gravity G of the body and the centre of buoyancy B must lie in the same vertical line [see fig.21(a)].

Centre of gravity : The centre of gravity of an object is the point at which the weight may be considered to act.

Centre of buoyancy : The centre of buoyancy of the object is located at the centre of gravity of the volume of the displaced liquid. It is the point through which the upward buoyant force seems to act.

* for additional knowledge

If a floating body is slightly displaced from its equilibrium position by applying an external force, it gets slightly tilted. By tilting the floating body, the shape of the liquid displaced changes, thus, its initial centre of buoyancy B shifts to a new position B' towards the leaning side [see fig.21(b)]. The vertical line through the new position B' meets the line joining G and B (the initial vertical line) at a point M . This point is called 'meta centre'.

In tilted position, the weight W and buoyant force F_B do not act in the same vertical line [see fig.21(b)]. This produces a rotation that may or may not restore the body to its equilibrium position.

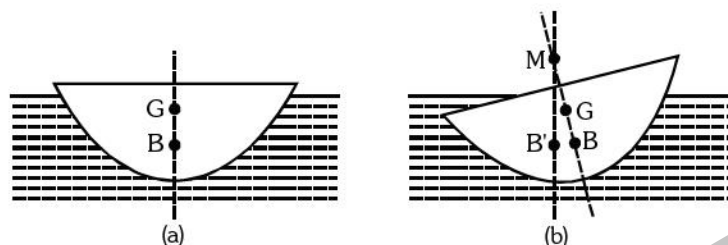


Fig.21 Equilibrium of a floating body

Depending on the position of the meta centre, the floating body may have three types of equilibrium :

- (1) Stable equilibrium (2) Unstable equilibrium (3) Neutral equilibrium

Stable equilibrium : If the centre of gravity G of the body lies below the meta centre M [see fig.22(a)], the equilibrium is stable. This means on tilting the floating body, it has the tendency to get back to its original untilted position. This is possible when the body is heavily loaded at its bottom.

Unstable equilibrium : If the centre of gravity G of the body lies above the meta centre M [see fig.22(b)], the equilibrium is unstable. This means on tilting the floating body, it has the tendency to go further away from its original untilted position. This is possible when the body is heavily loaded at its top.

Neutral equilibrium : If the meta centre M coincides with the centre of gravity G of the body [see fig.22(c)], the equilibrium is neutral. This means on tilting the floating body, it has no tendency to go towards or go away from its original untilted position. That is, on tilting the body remains floating in the tilted position. This is possible when the mass of the body is distributed uniformly over the entire volume.

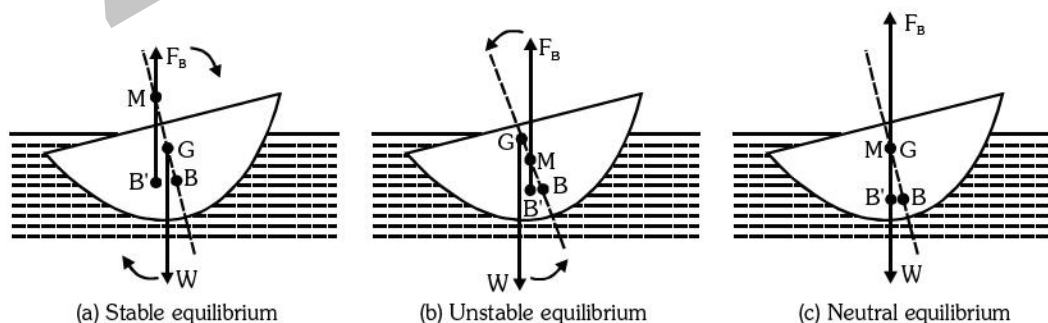


Fig.22 Different types of equilibrium for a floating body

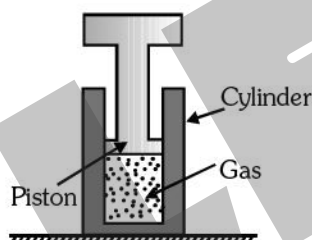
Important Notes

ALLEN

EXERCISE

Multiple choice questions

- A man of mass 60 kg stands on a weighing machine of area 225 m^2 . The pressure exerted by him is (take $g = 10 \text{ ms}^{-2}$)
 (1) 26666.7 Nm^{-2} (2) 266.67 Nm^{-2}
 (3) 26.667 Nm^{-2} (4) 2.67 Nm^{-2}
- A door of dimensions $2 \text{ m} \times 1.2 \text{ m} \times 0.06 \text{ m}$ is acted upon by a certain force due to the air inside the room, whose pressure is 10^5 Pa . The magnitude of the force is
 (1) $2.4 \times 10^5 \text{ N}$ (2) 2.4 dyne (3) 2.4 kN (4) 24 N
- The combustion chamber of a bike has an area of cross-section 16 cm^2 . A pressure of 400 Pa acts on it. Find force exerted on bike.
 (1) 64 N (2) 6.4 N (3) 0.64 N (4) 0.064 N
- The given apparatus shows a heavy piston supported by gas trapped in a cylinder. The cross-sectional area of the piston is $4.0 \times 10^{-4} \text{ m}^2$. The pressure of the gas inside the cylinder is $1.5 \times 10^5 \text{ Pa}$ and atmospheric pressure is $1.0 \times 10^5 \text{ Pa}$. Find the mass of the piston (Take $g = 10 \text{ m s}^{-2}$).



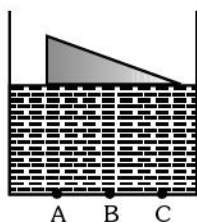
- The given figure shows two shoulder bags, one with a thin strap, and the other with a wide strap.
 (1) 1 kg (2) 2 kg (3) 3 kg (4) 4 kg



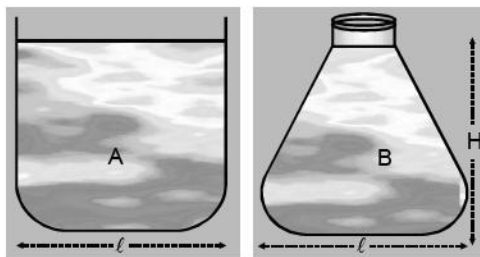
If both bags are equally heavy, the sling bag with the wide strap will be more comfortable to carry because

- (1) the thin strap has a greater mass per unit length
 - (2) the thin strap causes greater force to be exerted
 - (3) the wide strap allows friction to be spread over a bigger area, thus reducing the force between the shoulder and the strap
 - (4) the wide strap enables the weight of the bag to be spread over a bigger area, thus reducing the pressure on the shoulder
- Hydraulic brakes work on
 (1) Pascal's law (2) Archimedes' principle (3) Newton's law (4) Bernoulli's theorem
 - To lift an automobile of 1600 kg, a hydraulic pump with a larger piston 800 cm^2 in area is employed. If the area of the smaller piston is 10 cm^2 , the force that must be applied on it is
 (1) 20 N (2) 20 kgf (3) 200 kgf (4) 2000 N

8. An object of uniform density is allowed to float on water kept in a beaker. The object has triangular cross-section as shown in the figure. If the water pressure measured at the three points A, B and C below the object are P_A , P_B and P_C respectively, then

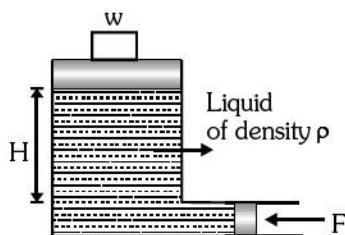


- (1) $P_A > P_B > P_C$ (2) $P_A < P_B < P_C$ (3) $P_A = P_B = P_C$ (4) $P_A = P_C < P_B$
9. In a stationary homogeneous liquid
- (1) pressure is the same at all points at the same level
 - (2) pressure is the same at all points
 - (3) pressure depends on the direction
 - (4) pressure is independent of any atmospheric pressure on the upper surface of the liquid
10. **Assertion :** It is difficult to stop bleeding from a cut in the body at high altitudes.
Reason : The atmospheric pressure at high altitude is lesser than the blood pressure.
- (1) Both assertion and reason are correct and reason is the correct explanation of assertion.
 - (2) Both assertion and reason are true but reason is not the correct explanation of assertion.
 - (3) Assertion is true but reason is false.
 - (4) Assertion is false but reason is true.
11. Density of ice is σ and that of water is ρ . What will be the decrease in volume when a mass M of ice melts?
- (1) $\frac{M}{\sigma - \rho}$ (2) $\frac{\sigma - \rho}{M}$ (3) $M \left[\frac{1}{\sigma} - \frac{1}{\rho} \right]$ (4) $\frac{1}{M} \left[\frac{1}{\rho} - \frac{1}{\sigma} \right]$
12. The relative density of a solid with respect to a liquid is $4/5$ and relative density of the liquid with respect to water is $10/9$. The buoyant force exerted by a liquid on a solid immersed in it is equal to the weight of the liquid displaced by the solid. Specific gravity of solid with respect to water is
- (1) $18/25$ (2) $8/9$ (3) 0.56 (4) 1.8
13. A tank 2 m high is half filled with water and then filled to the top with oil of density 0.80 g/cc . What is the pressure at the bottom of the tank due to these liquids only? (Take $g = 10 \text{ ms}^{-2}$)
- (1) $1.8 \times 10^3 \text{ Nm}^{-2}$ (2) $0.9 \times 10^3 \text{ Nm}^{-2}$ (3) $1.8 \times 10^4 \text{ Nm}^{-2}$ (4) $0.9 \times 10^4 \text{ Nm}^{-2}$
14. Two vessels A and B have the same base area and contain water to the same height, but the mass of water in A is four times that in B. The ratio of the liquid thrust at the base of A to that at the base of B is

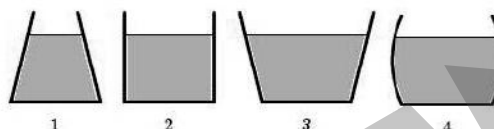


- (1) 4 : 1 (2) 2 : 1 (3) 1 : 1 (4) 16 : 1

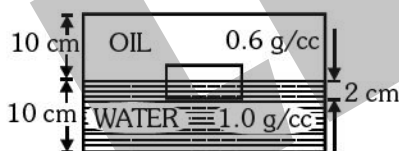
15. A heavy load W is supported on a platform of area S by applying a force F on a small piston of area $\frac{S}{10}$. The value of F for equilibrium is



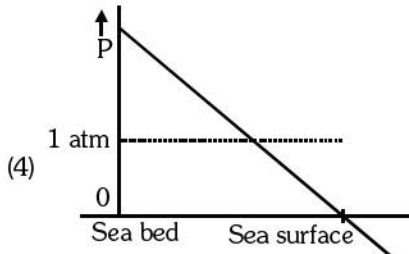
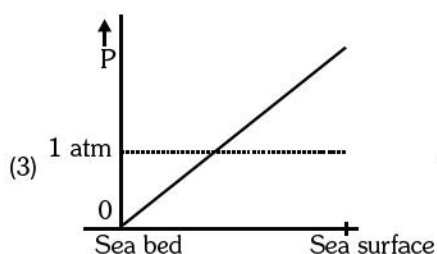
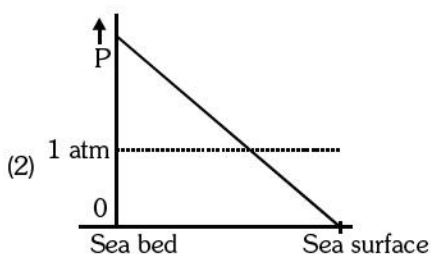
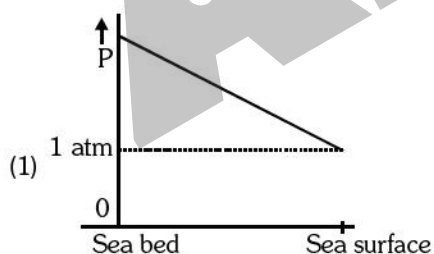
- (1) $\frac{W}{10}$ (2) $\frac{W + \rho g H S}{10}$ (3) $\frac{W - \rho g H S}{10}$ (4) $10 W$
16. The vessels shown below all contain water to the same height. Rank them according to the pressure exerted by the water on the vessel bottoms, least to greatest.



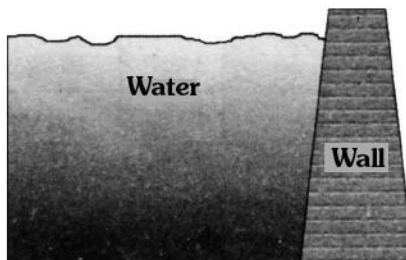
- (1) 3, 4, 2, 1 (2) 4, 3, 2, 1 (3) 2, 3, 4, 1 (4) All pressures are the same
17. A cubical block of side 10 cm floats at the interface of an oil and water. The pressure above that of atmosphere at the lower face of the block is



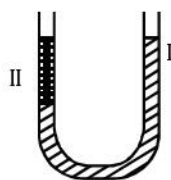
- (1) 200 N/m^2 (2) 680 N/m^2 (3) 400 N/m^2 (4) 800 N/m^2
18. A body submerged in the sea was brought up slowly from the sea bed to the sea surface. Variation of pressure on the body with decrease in the depth of sea is shown in the figures below. Which of these is correct?



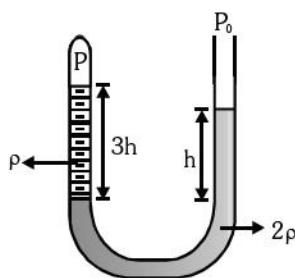
19. The given figure shows the cross-section of a dam and its reservoir. The widening of the wall towards the bottom is because of :



- (1) increase in pressure with depth of water
 (2) decrease in pressure with depth of water
 (3) decrease in density of water
 (4) increase in density of water
20. A dam has a height H and a width b . Assuming that the water level reaches the top, find the average force exerted on the dam for $H = 60$ m and $b = 200$ m.
- (1) 3×10^8 N (2) 4.2×10^9 N (3) 2.3×10^{10} N (4) 3.6×10^9 N
21. At a depth of 1000 m in an ocean, what is the gauge pressure? (The density of sea water is $1.03 \times 10^3 \text{ kg m}^{-3}$; $g = 10 \text{ m s}^{-2}$)
- (1) 1.03×10^5 Pa (2) 2.06×10^5 Pa (3) 1.03×10^7 Pa (4) 2.06×10^7 Pa
22. To obtain the absolute pressure from the gauge pressure
- (1) subtract atmospheric pressure (2) add atmospheric pressure
 (3) subtract 273 (4) add 273
23. A U-tube of uniform cross-section shown in figure is partially filled with liquid I. Another liquid II which does not mix with I is poured into one side. The liquid levels of the two sides is found the same, while the level of liquid I has risen by 2 cm. If the specific gravity of liquid I is 1.1, the specific gravity of liquid II must be

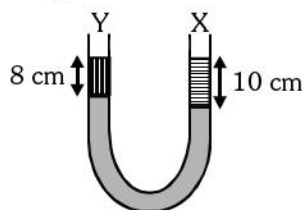


- (1) 1.2 (2) 1.1 (3) 1.3 (4) 1.0
24. In the figure shown

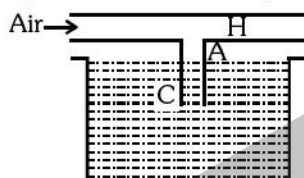


- (1) $P < P_0$ (2) $P > P_0$ (3) $P = P_0$ (4) $P = 0$

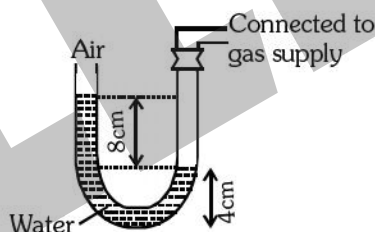
25. A liquid X of density 3.36 g/cm^3 is poured in a U-tube, which contains Hg ($\rho_{\text{Hg}} = 13.6 \text{ g/cm}^3$). Another liquid Y is poured in left arm with height 8 cm. Upper levels of X and Y are same. What is density of Y?



- (1) 0.8 g/cc (2) 1.2 g/cc (3) 1.4 g/cc (4) 1.6 g/cc
26. Mercury is a convenient liquid to use in a barometer because
- (1) it is a metal (2) it has a high boiling point
(3) it expands little with temperature (4) it has a high density
27. A capillary tube C dipped in a liquid that wets it as shown in figure. If we blow air through the horizontal tube H, then what will happen to the liquid column in the capillary tube?



- (1) Level will fall below A. (2) Level will rise above A.
(3) Level will remain at A. (4) It is difficult to predict.
28. A manometer is connected to a gas supply. Pressure can be measured in cm of water. The pressure of the gas is



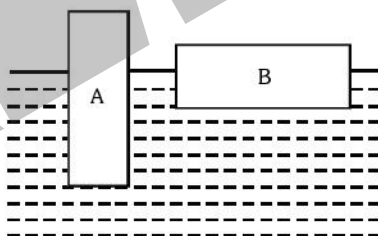
- (1) 8 cm of water more than atmospheric pressure.
(2) 12 cm of water more than atmospheric pressure.
(3) 8 cm of water less than atmospheric pressure.
(4) 12 cm of water less than atmospheric pressure.
29. A solid of mass 1.6 kg and density $2.4 \times 10^3 \text{ kgm}^{-3}$ is completely immersed in water. The loss of weight is
- (1) 0.66 N (2) 0.66 kg wt (3) 6.6 kg wt (4) 66 N
30. A body floats in a liquid contained in beaker. The whole system as shown in figure falls freely under gravity. The upthrust on the body is



- (1) zero.
(2) equal to the weight of the liquid displaced.
(3) equal to the body weight in air.
(4) equal to the weight of the immersed portion of the body.

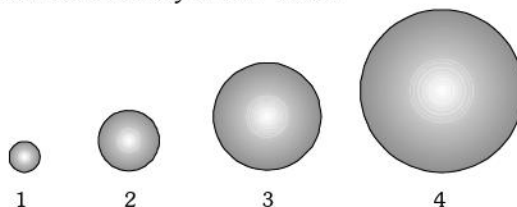
31. A small block of wood of relative density 0.5 is submerged in water. When the block is released, it starts moving upwards. The acceleration of the block is ($g = 10 \text{ ms}^{-2}$)
 (1) 5 ms^{-2} (2) 10 ms^{-2} (3) 7.5 ms^{-2} (4) 15 ms^{-2}
32. A sealed packet of mass 500 g has density 1.43 g cm^{-3} . When placed in alcohol (density 0.8 g cm^{-3}) the upthrust on the packet will be (take $g = 10 \text{ m/s}^2$)
 (1) 250 gf (2) 280 gf (3) 350 gf (4) 300 gf
33. A body of density d_1 is counterpoised by Mg of weights of density d_2 in air of density d . Then the true mass of body is
 (1) M (2) $M\left(1 - \frac{d}{d_2}\right)$ (3) $M\left(1 - \frac{d}{d_1}\right)$ (4) $\frac{M(1 - d/d_2)}{(1 - d/d_1)}$
34. A coil of wire of cross section 0.75 mm^2 weighs 125 g in air and 115 g in water. The length of the coil in cm is
 (1) $\frac{10^2}{0.75} \text{ cm}$ (2) $\frac{10^5}{0.75} \text{ cm}$ (3) $\frac{10^5}{75} \text{ cm}$ (4) $\frac{10^3}{75} \text{ cm}$
35. An object of mass 4 kg and density $2 \times 10^3 \text{ kg m}^{-3}$ is completely immersed in water, its apparent weight will be
 (1) 2 kg wt (2) 20 kg wt (3) 1 kg wt (4) 10 kg wt
36. A solid has a mass 39 kg. It loses $\frac{1}{3}$ rd of its weight when immersed in water. Its volume will be
 (1) $1.3 \times 10^{-3} \text{ m}^3$ (2) $13 \times 10^{-3} \text{ m}^3$ (3) $13 \times 10^{-2} \text{ m}^3$ (4) 13 m^3
37. A piece of pure gold ($\rho = 19.3 \text{ g cm}^{-3}$) is suspected to be hollow from inside. It weighs 77.2 g in air and 71.2 g in water. The volume of the hollow portion in gold will be
 (1) 1 cm^3 (2) 2 cm^3 (3) 3 cm^3 (4) 4 cm^3
38. When a body is weighed in a liquid, the loss in its weight is not equal to
 (1) Weight of liquid displaced by the body.
 (2) Weight of water displaced by the body.
 (3) The difference in weights of the body in air and liquid.
 (4) The upthrust of liquid on the body.
39. A solid has a volume of 8 cm^3 . When weighed on a spring scale calibrated in grams, the scale indicates 20 g. What does the scale indicate if the object is weighed while immersed in a liquid of density 2 g/cm^3 ?
 (1) 16 g (2) 10 g (3) 12 g (4) 4 g
40. An iron cube of mass 5 kg and sides 10 cm is inside water. What will be its apparent weight?
 (1) 39.2 N (2) 58.8 N (3) 49 N (4) 24.5 N
41. A log of wood of mass 120 kg floats in water. The weight that can be put on the raft to make it just sink, should be (density of wood = 600 kg/m^3)
 (1) 80 kg (2) 50 kg (3) 60 kg (4) 30 kg
42. Two solids A and B float in water. It is observed that A floats with $\frac{1}{2}$ of its body immersed in water and B floats with $\frac{1}{4}$ of its volume above the water level. The ratio of the density of A to that of B is
 (1) 4:3 (2) 2:3 (3) 3:4 (4) 1:2

43. When a sphere is floating in water, its $\frac{1}{3}$ rd part is outside the water, and when sphere is floating in unknown liquid, its $\frac{3}{4}$ th part is outside the liquid, then density of liquid is
- (1) $\frac{4}{9}$ gm/cc (2) $\frac{9}{4}$ gm/cc (3) $\frac{8}{3}$ gm/cc (4) $\frac{3}{8}$ gm/cc
44. A piece of wood of R.D. 0.25 floats in a pail containing oil of R.D. 0.81. The fraction of volume of the wood above the surface of the oil is
- (1) 0.31 (2) 0.69 (3) 0.21 (4) 0.79
45. A solid floats in water with $\frac{3}{4}$ th of its volume below the surface of water. The density of the solid will be
- (1) 75 kgm⁻³ (2) 750 kgm⁻³ (3) 75×10^2 kgm⁻³ (4) 75×10^3 kgm⁻³
46. The density of ice is 0.918 g cm⁻³ and that of water is 1.03 g cm⁻³. An iceberg floats with a portion of 224 cm³ outside the surface of water. The total volume of the iceberg is
- (1) 1030 cm³ (2) 1545 cm³ (3) 2060 cm³ (4) 2575 cm³
47. A man of weight 40 kg floats on water in a lake. His apparent weight is
- (1) 40 kg (2) 35 kg (3) zero (4) 20 kg
48. A wooden cube just floats inside water when a 200 g mass is placed on it. When the mass is removed the cube is 2 cm above water level. The side of cube is
- (1) 5 cm (2) 10 cm (3) 15 cm (4) 20 cm
49. A boat having a length of 3 metre and breadth 2 metre is floating on a lake. The boat sinks by 1 cm when a man gets on it. The mass of the man is
- (1) 60 kg (2) 62 kg (3) 72 kg (4) 128 kg
50. Two identical blocks of ice float in water as shown. Then

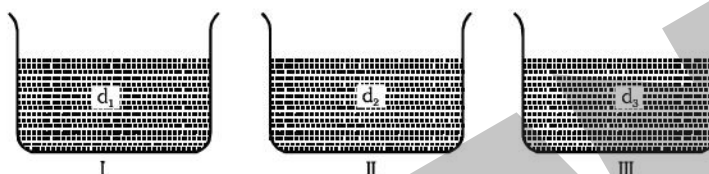


- (1) block A displaces a greater volume of water since the pressure acts on a smaller bottom area.
 (2) block B displaces a greater volume of water since the pressure is less on its bottom.
 (3) the two blocks displace equal volumes of water since they have the same weight.
 (4) block A displaces a greater volume of water since its submerged end is lower in the water.
51. A vessel contains oil (density $\rho_0 = 0.8$ g cm⁻³) over mercury (density $\rho_{Hg} = 13.6$ g cm⁻³). A homogeneous sphere floats with half its volume immersed in mercury and the other half in oil. The density of material of sphere in g cm⁻³ is
- (1) $(\rho_0 + \rho_{Hg})\frac{1}{2}$ (2) $\rho_0 + \rho_{Hg}$ (3) $\rho_{Hg} - \rho_0$ (4) $\frac{\rho_0 \rho_{Hg}}{\rho_{Hg} + \rho_0}$
52. A glass stopper suspended from the hook of a spring balance and immersed in water reads 100 gf. When a cork of volume 20 cm³ is tied to the glass stopper and then the combination is immersed in water, the reading of spring balance will be
- (1) more than 100 gf (2) equal to 100 gf (3) less than 100 gf (4) none of the above

53. Sonam has 4 solid metallic balls, all of equal weight. The sizes of the 4 balls are as shown below. If ball 2 sinks in water, which of the other balls will definitely sink in water?



- (1) Only ball 1 (2) Only ball 3
(3) Both ball 1 and ball 4 (4) All the other balls -1, 3 and 4
54. A large iron body of mass 2 kg and volume $2.5 \times 10^{-3} \text{ m}^3$ is dipped in water. Will it float or sink?
(1) Float (2) Sink
(3) Float & then sink (4) Cannot be determined
55. An object of density d is immersed in three different liquids of densities d_1 , d_2 and d_3 such that $d_3 < d_1 < d < d_2$



- (1) It will sink in liquid III and float in liquid I
(3) It will sink in liquid I and float in liquid III
(2) It will sink in liquid III and float in liquid II
(4) It will sink in liquid II and float in liquid I
56. A block weighs 15 N in air. It weighs 12 N when immersed in water and 13 N when immersed in another liquid. The relative density of the block and liquid will be
(1) $\frac{3}{2}$; 5 (2) $\frac{2}{3}$; $\frac{1}{5}$ (3) 5 ; $\frac{2}{3}$ (4) $\frac{1}{5}$; $\frac{3}{2}$
57. A piece of steel has a weight W in air, W_1 when completely immersed in water and W_2 when completely immersed in an unknown liquid. The relative density (specific gravity) of liquid is
(1) $\frac{W - W_1}{W - W_2}$ (2) $\frac{W - W_2}{W - W_1}$ (3) $\frac{W_1 - W_2}{W - W_1}$ (4) $\frac{W_1 - W_2}{W - W_2}$
58. A solid weighs 32 gf in air and 28.8 gf in water. The R.D. of the solid is
(1) 8.9 (2) 10 (3) 29.12 (4) 20
59. An ice cube holding a solid steel ball floats in a cup of water. After all the ice melts, the level in the cup will
(1) rise
(2) fall
(3) remain unchanged
(4) cannot be confirmed without knowing density of steel ball
60. An ice cube with an embedded cork floats in a cup of water. If all ice melts, there will be
(1) drop in level (2) rise in level
(3) no change in level (4) can drop or rise based on temperature

ANSWERS

Que.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Ans.	4	1	3	2	4	1	2	3	1	1	3	2	3	3	2	4	4	1	1	4
Que.	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
Ans.	3	2	2	1	1	4	2	1	2	1	2	2	4	3	1	2	2	2	4	1
Que.	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
Ans.	1	2	3	2	2	3	3	2	1	3	1	3	1	1	2	3	2	2	2	3